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ScienceDirect

Acta Astronautica 64 (2009) 395–402

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

Roadmap of Indian space transportation

B.N. Suresh

Vikram Sarabhai Space Centre, Thiruvananthapuram, India

Received 5 December 2007; received in revised form 16 September 2008; accepted 22 September 2008
Available online 30 November 2008

Abstract

The operational Indian space transportation system provides launch support for the entire range of remote sensing and communication satellites up to 2.5 t, giving precise orbital injection. In order to meet the national requirements of launching heavier payloads as well as to reduce the launch cost, long-term technology developments have been initiated. This paper delineates briefly the plans for future developments in respect of advanced launch transport systems and facilities.

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1. Introduction

Indian space transportation system has achieved the capabilities to launch remote sensing (IRS) and communication (INSAT) series of satellites. These are the two major operational space systems in India. The indigenously designed and developed operational launch vehicles namely Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV) have launched operational satellites which have been providing the diverse space services to the country, like remote sensing, natural resource management, weather monitoring, telecommunication, television broadcasting, tele-medicine, tele-education, village resource centres, etc. Up till now the PSLV has launched 10 remote sensing satellites, having the highest payload mass of 1600 kg in Sun Synchronous Polar Orbit (SSPO). Further, the GSLV has launched four satellites of GSAT type, the heaviest mass of payload being 2240 kg in Geo-stationary Transfer Orbit (GTO). PSLV has also demonstrated its versatility to launch a satellite into GTO [1]. In each of these launches, the orbit injection accuracies have met the stringent specifications laid down as per mission specification.

Having achieved the operational capabilities, the future roadmap has been defined for the Indian space transportation system. The technology developments for performance improvement of the operational vehicles of launch heavier payloads to meet the national needs as well as to launch commercial satellites is the first priority. Parallely, the long-term technology developments have also been initiated for the development of advanced launch vehicles [2]. Many of the Indian geo-stationary satellites exceed 2.5 t, which is beyond present capability of GSLV and is expected to grow to 4 t, in the near future. To meet this demand, ISRO has undertaken the development of GSLV Mk-III, which will have capability to place payloads of 4 t in GTO and 10 t in Low Earth Orbit (LEO). This vehicle is targeted to make the first launch in the next two years. Currently, developments in launch vehicle technology all over the globe are directed towards reduction in the cost of launch by an order of magnitude. Towards this, ISRO has initiated the development of Reusable Launch Vehicles (RLVs) including the possible use of

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E-mail address: bn_suresh@vssc.gov.in

0094-5765/$ - see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.actaastro.2008.09.009

air breathing engines. In addition, detailed feasibility studies have been carried out on manned mission to explore new scientific and technological frontiers. This demands for man rating as well as improved safety and reliability for the launch vehicle. This paper explains in brief the efforts by ISRO to achieve the objectives of roadmap defined for the Indian space transportation.

2. Roadmap of Indian launch vehicle programme

One of the important objectives of the defined roadmap is to progressively implement the performance improvements of operational launch vehicles, PSLV and GSLV, to meet the higher payload demand [3]. This will be achieved by adding new modules, improved propulsive stages, optimization of vehicle stage structures, and avionics in addition to the minimization of launch cost through optimization of materials and fabrication. In parallel the developments are being pursued to launch 4 t class of satellites in to GTO by the cost effective launch vehicle, GSLV-Mk III. In order to use space systems effectively for the benefit of humankind, cost of space transportation system has to be reduced by two orders of magnitude compared to the present cost. This is feasible by routine access through Single Stage to Orbit (SSTO) with air breathing propulsion system which substantially reduces the launch cost. For this purpose, long-term technology developments required to achieve SSTO have been initiated. This is planned by a series of progressive technology development programmes through RLV-technology demonstrator, air breathing technology demonstrator, Two Stage to Orbit (TSTO) with air breathing system. Fig. 1 gives the road map of Indian space transportation addressing various developmental programmes planned for the next 25 years.

In order to support these programmes, the various technology developments in advanced areas like cost effective propulsive systems namely semi-cryogenic engines and high power cryogenic engines, high strength-to-weight ratio materials, hot structures and advanced testing facilities are being pursued. Mission to moon is planned to provide opportunities for space exploration. In addition, human space mission is also being studied to explore new frontiers, both scientific and technological which will provide wide range of economic, political and cultural benefits as well as an investment for future. The various developments planned for achieving this vision is given in the subsequent sections.

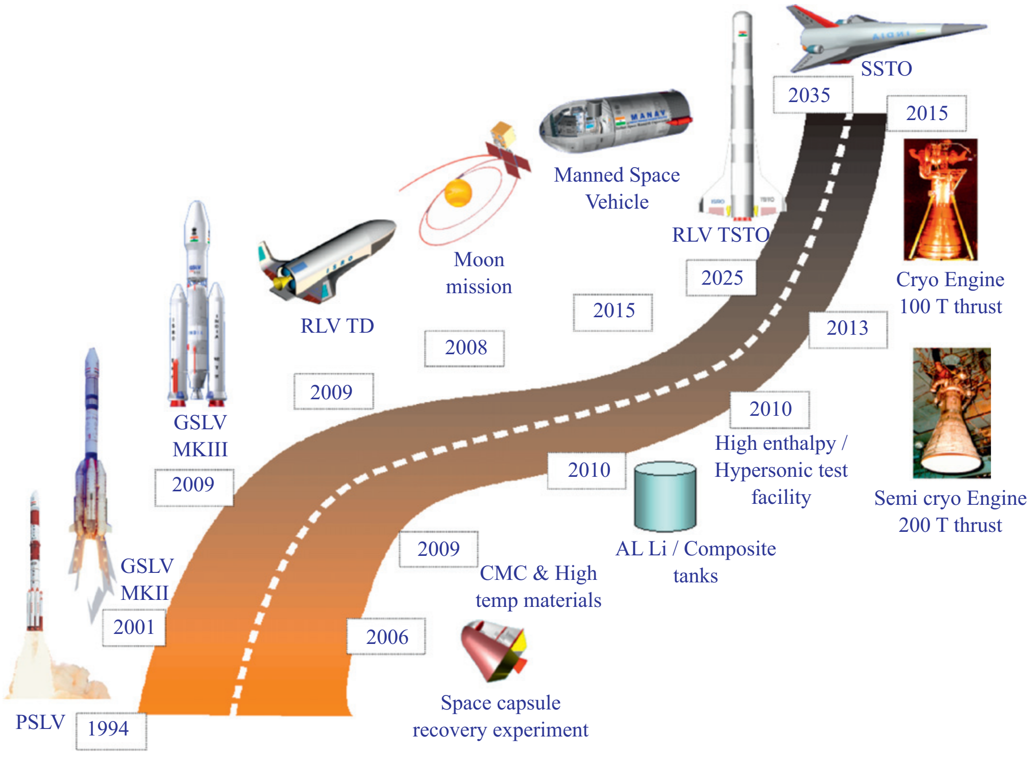


Fig. 1. Indian space transportation road map.

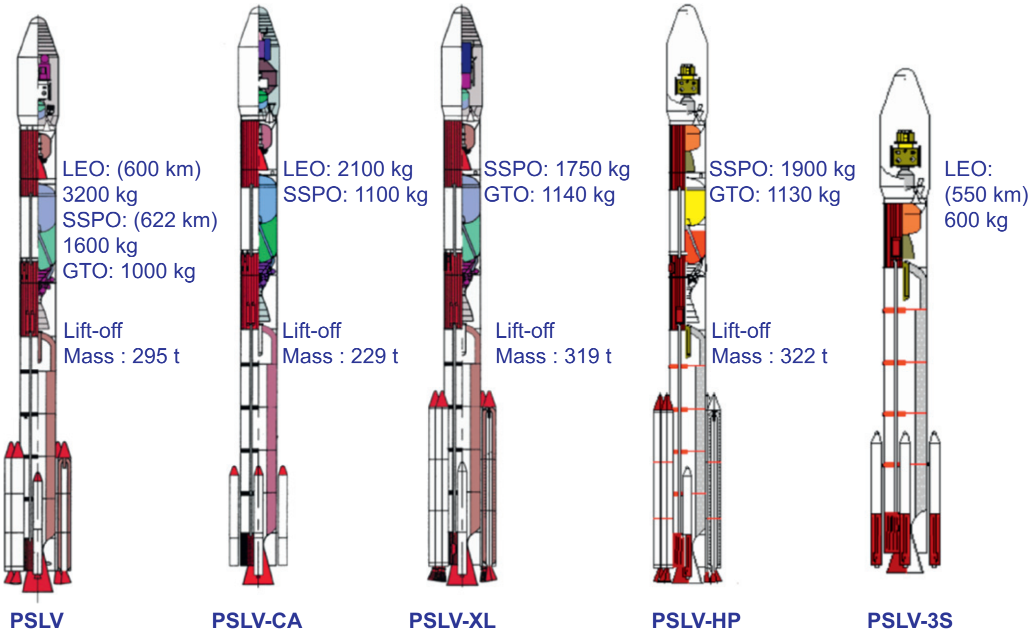


Fig. 2. PSLV variants and payload capability.

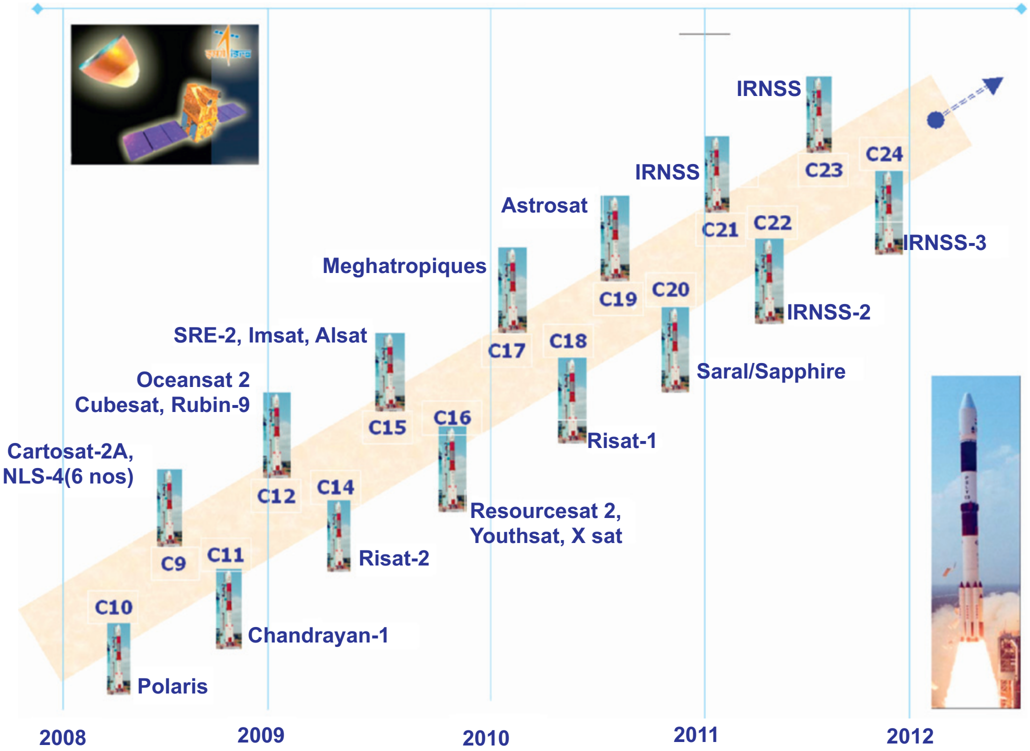
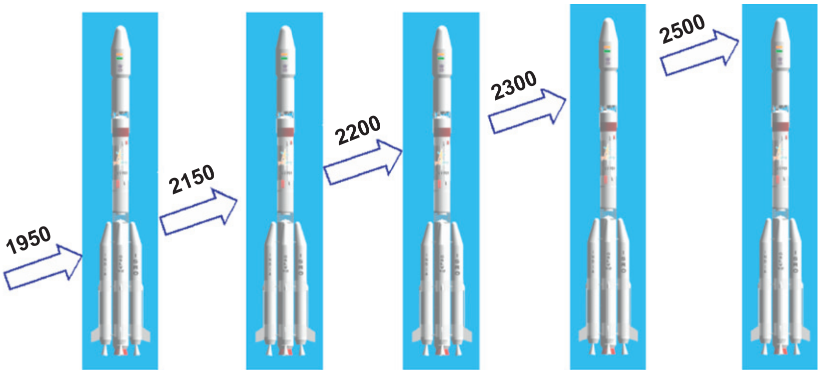


Fig. 3. PSLV launch manifest.



	MK-II	MK-II CUS	MK-II A	MK-II A CUS	MK-II C
GS-1	4L40+S139	4L40+S139	4L40+S139	4L40+S139	4L40+S139
GS-2	L 37.5	L37.5	L37.5	L37.5	L40
GS-3	C12	CUS12	C15	CUS15	C15/CUS15
GS-4					PAM

Fig. 4. GSLV variants.

3. Operational programme

3.1. PSLV

Eleven consecutive successful launches of PSLV have taken place which have injected satellites with different sizes and masses to a wide range of mission defined orbits. This versatile vehicle has launched satellites in different SSPO, GTO, and multi-satellite mission up to four satellites, multi-orbits in single mission and two dedicated commercial satellites. In order to optimize the launch cost of PSLV for lesser payload mass missions as well as high payload missions, different PSLV configuration variants have been envisaged as shown in Fig. 2.

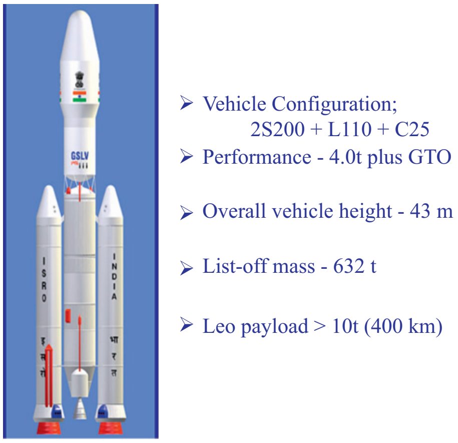
These configurations provide wide variations in payload capabilities ranging from 600 kg in LEO to 1900 kg in SSPO. Core alone configuration without strap-on motors is designed to launch two satellites of 400 kg in LEO. To minimize the launch cost of 500 kg class of satellites in LEO, PSLV in three-stage configuration without strap-on motors and liquid stage is being developed. The PSLV launch manifest as envisaged up to 2012 is given in Fig. 3.

3.2. GSLV

GSLV has successfully completed two developmental flights and two operational flights with communication satellites. GSLV is configured to launch navigation satellites directly into 19,000 km circular orbit. This calls for the development of a payload assist module (PAM) configured around the fourth stage of PSLV. The conventional GSLV launches the PAM along with payload into an elliptic orbit and the PAM is used to circularize the orbit as part of launch vehicle mission. The mission management of long duration mission of the launch vehicle to the order of 3–4 h compared to the present 20 min is planned for this mission. The GSLV flight with indigenous cryo engine, advanced avionics systems configured with indigenous onboard computers and with 4 m composite payload fairing to launch the satellite of 2.5 t mass is planned in the coming years. The GSLV also envisages different configuration variants to cater to different mission requirements and the details are given in Fig. 4.

4. GSLV Mk-III development

Development of GSLV Mk-III is initiated to meet the demands of launching 4 t class of spacecraft as well as to offer cost effective launch services. Fig. 5 shows the configuration of GSLV Mk-III. It is a three stage vehicle with two solid strap-on motors of 200 t propellant loading and liquid core of 110 t propellant loading with the clustering of two engines. The upper stage with a cryo engine has a propellant loading of 25 t. Important technology developments in this vehicle are: (a) one of the large solid propellant boosters in the globe, (b) a flex nozzle control system for the large solid booster, (c) liquid stage with clustered engines, (d) a high thrust cryo engine operating in gas generator cycle, (e) composite



- Vehicle Configuration;
  2S200 + L110 + C25
- Performance - 4.0t plus GTO
- Overall vehicle height - 43 m
- List-off mass - 632 t
- Leo payload > 10t (400 km)

Fig. 5. Configuration of GSLV Mk-III.

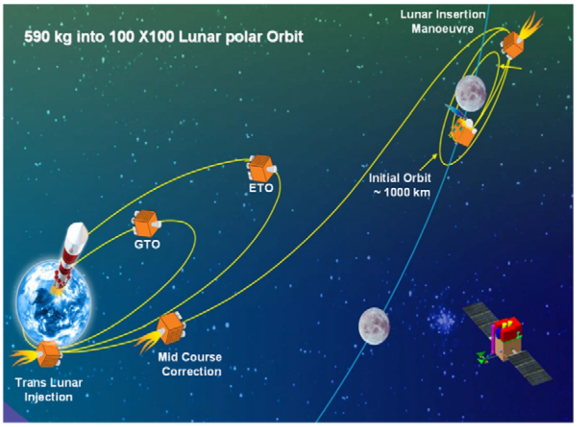


Fig. 6. Mission to moon.

structures, (f) improved failure detection and isolation (FDI) schemes in avionics and control systems, and (g) miniaturized avionics and TTC packages with improved band-width. The developmental flight of GSLV Mk-III is expected within the next two years.

5. Mission to moon

In order to expand the scientific knowledge about the moon, upgrade Indian technologies capability and to promise opportunities for planetary research, mission to moon is planned. The mission is to achieve 100×100 km lunar polar orbit with the satellite mass of 550 kg with two years life time. The launch trajectory is given in Fig. 6.

The payload contains lunar terrain mapping camera, X-ray spectrometer, stereo imager, imaging spectrometer, etc. The technologies being developed are interplanetary trajectory, the mission strategy, power management, thermal control, onboard autonomy, deep space spacecraft control and communication link and special mechanisms.

6. Technologies for advanced launch vehicles

Indian launch vehicle programme constantly strives to improve technologies to meet the long-term needs. Currently identified technologies are realization of (1) large cryogenic upto 500 kN thrust and semi-cryogenic boosters, (2) air breathing propulsion, and (3) building block for RLV. High specific impulse propellants, high strength materials like Al–Li alloy, metal matrix composites, supersonic and hypersonic wind tunnel facilities, CFD tools for internal and external flow field analysis, smart actuator system, robotics, fault tolerant onboard computers and advanced navigation sensors are some of the elements of advanced technologies. Further, in order to explore new frontiers in science and technology, studies for manned mission are also in the agenda.

6.1. Air breathing propulsion

Reducing requirement of propellant is fundamental to low cost access to space, as propellant forms about 85% of launch vehicle mass out of which bulk of the propellant is oxidizer. In air breathing propulsion, the entire requirement of oxidizer need not be carried along with the vehicle.

ISRO has initiated the development of Dual Mode Ram Jet (DMRJ) based on the detailed studies of the options available. Extensive theoretical [4] and experimental [5] studies have been carried out on various aspects of air breathing propulsion. While the earlier studies focused on rocket based combined cycle, the current focus is on the scramjet engine cycle where the critical technologies and high temperature materials are crucial and are being addressed. ISRO has demonstrated successfully a stable supersonic combustion through a series of ground tests for an equivalent flight Mach number of 2 to 10. Fuel injection, mixing, ignition and flame holding as air travels at speeds greater than 1 km/s within combustion chamber is often equated to ‘lighting candle in hurricane’. Theoretical studies including extensive use of CFD tools have supported design and analysis.

DMRJ-Flight test demonstrator is conceived as a simple and cost effective flight demonstrator vehicle, as it uses an existing sounding rocket as a carrier. It is planned to flight test a scramjet engine in flight Mach number range of 6–7. Realization of the vehicle and

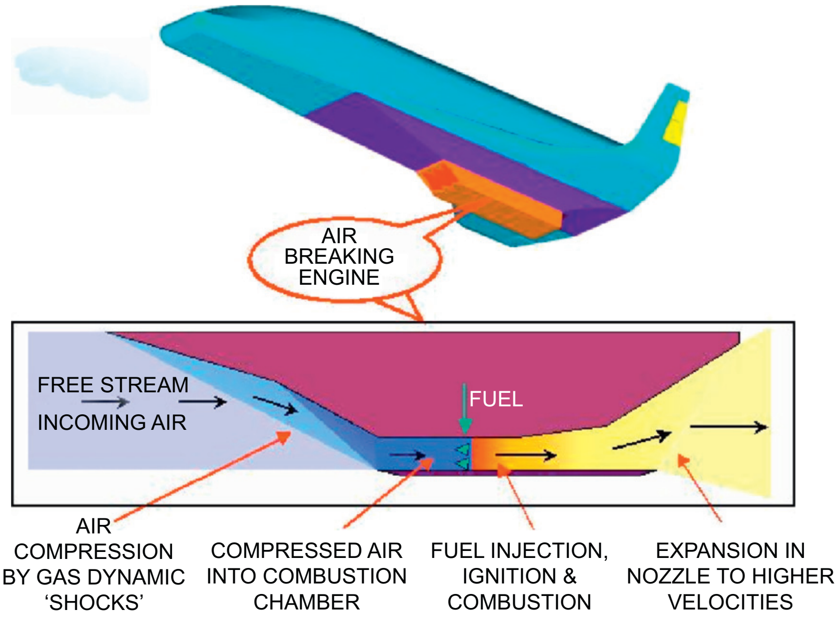

AIR BREAKING ENGINE
FREE STREAM INCOMING AIR
FUEL
AIR COMPRESSION BY GAS DYNAMIC 'SHOCKS'
COMPRESSED AIR INTO COMBUSTION CHAMBER
FUEL INJECTION, IGNITION & COMBUSTION
EXPANSION IN NOZZLE TO HIGHER VELOCITIES

Fig. 7. Advanced reusable launch vehicle using air breathing propulsion.

engine is making rapid progress. Also, a major test facility capable of up to four times the flow rates of the current scramjet test programme is coming up. This scramjet propulsion test facility can test and evaluate scramjet combustors up to flight Mach number eight.

Development of air breathing propulsion technology for TSTO-RLV is envisaged in a progressive manner. Starting with DMRJ-FTD flights for 0.1 t class ram-scramjet engine, RLV-TD is planned to use 1 t class of turbojet, ramjet and scramjet engines. These technology developments would pave way for the subsequent design and development of bigger air breathing engines (of 10 t class and above) for use in advanced RLV. Fig. 7 illustrates the advanced reusable launch vehicle using the air breathing propulsion.

6.2. *Reusable launch vehicle*

The RLV aims to bring down the cost of placing a kg of payload into orbit by an order, through reuse of the vehicle systems. For an expandable launch vehicle (ELV), the cost of launching 1 kg to LEO is approximately $10,000–15,000. This is due to the fact that 67% of the ELV cost is that of hardware, which is expended. Also, for an ELV the payload fraction is approximately 15–20%. In an RLV, attempts will be made to reuse all systems. With an air-breathing engine as first stage the payload fraction can be improved to as low as 4%. With these, the cost per kg for LEO orbits can be brought down substantially to around $1000–2000.

Extensive studies on configuration options Single Stage to Orbit (SSTO)/Two Stage to Orbit (TSTO) have shown that with the current levels of technologies of propulsion and materials TSTO is feasible in the immediate future. Towards realizing the TSTO and associated new technologies, ISRO has undertaken the development of a RLV technology demonstrator. It has a wing-body configuration and its return flight will have high angles of attack in the upper atmosphere, in order to reduce the kinetic energy before reaching lower altitudes. It will use aerodynamic controls during the atmospheric flight. The entire flight will be autonomous. This RLV-TD will be designed using available technologies to start with, and will progressively adopt and test new technologies. In a brief period of about 3–5 years, RLV-TD will prove, in a cost effective way, the advanced technologies that are required for taking decisions regarding the route to be followed for design and development of the full scale TSTO-RLV. Presently the priority is assigned to understand and master the technologies related to hypersonic flight of a winged body configuration and will have fully autonomous operation through the intended mission.

Some of the technologies to be perfected through these trials are related to hypersonic aerothermodynamics, reusable thermal protection systems, design of reusable structures including control surfaces,

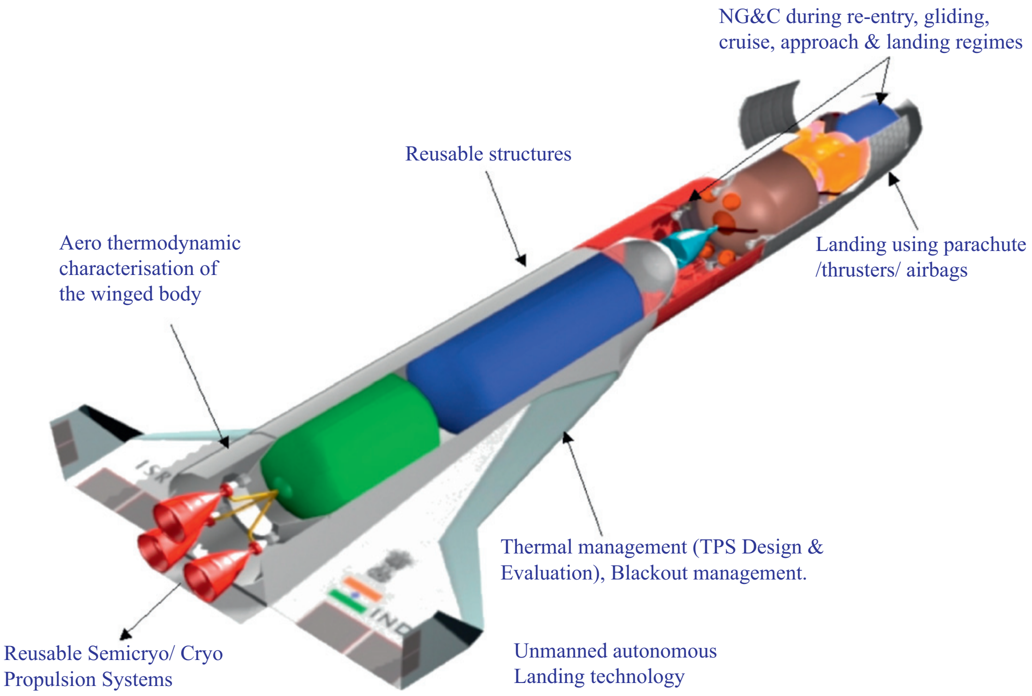

NG&C during re-entry, gliding, cruise, approach & landing regimes
Reusable structures
Aero thermodynamic characterisation of the winged body
Landing using parachute /thrusters/ airbags
Thermal management (TPS Design & Evaluation), Blackout management.
Reusable Semicryo/ Cryo Propulsion Systems
Unmanned autonomous Landing technology

Fig. 8. Reusable launch vehicle—new technologies.

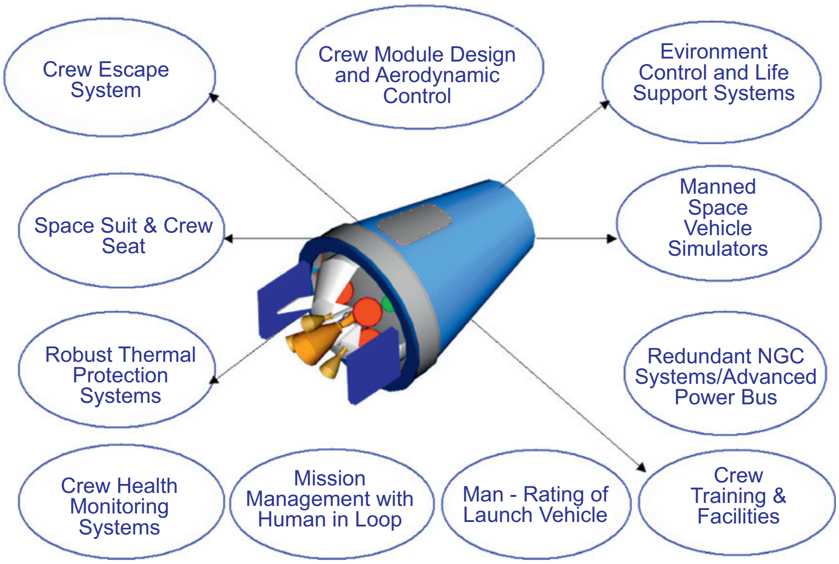

Crew Escape System
Crew Module Design and Aerodynamic Control
Evironment Control and Life Support Systems
Space Suit & Crew Seat
Manned Space Vehicle Simulators
Robust Thermal Protection Systems
Redundant NGC Systems/Advanced Power Bus
Crew Health Monitoring Systems
Mission Management with Human in Loop
Man - Rating of Launch Vehicle
Crew Training & Facilities

Fig. 9. Manned mission—new technologies.

autonomous flight management, NGC for re-entry and controlled descent, in-flight health monitoring system, and abort systems, as shown in Fig. 8. Subsequently RLV-TD will be used as a test-bed for evaluating new propulsion systems like the air-breathing SCRAMJET/RAMJET modules.

6.3. Studies on Indian manned space programme

The Indian Space Programme after crossing several major milestones including development and operationalization of launch vehicles, satellites for scientific research as well as exploiting the vantage point of space for a variety of applications relevant to national development is now poised to explore newer dimensions as a part of long-term goal. Such goals are not only meant to retrain the pre-eminence of India in space but also will ensure the rightful role in other emerging areas of space research such as planetary exploration and human presence in space. It is against this backdrop that ISRO has initiated in the recent past detailed studies on different options for a manned space mission.

The studies have indicated that it is possible to utilize the existing GSLV vehicle with necessary modifications for man rating. Development of a fully autonomous orbital vehicle with various necessary modules including the escape module is envisaged. Compared to an unmanned space vehicle a host of new technologies will be required to accomplish such a complex programme. In this context, a host of new technologies and systems like crew module, service module, launch escape systems, environmental control and life support systems, avionics system, etc. as shown in Fig. 9 are to be designed and developed.

7. Conclusions

India has operational satellite launch vehicles capable of launching precisely a wide variety of satellites at different defined orbits providing diverse space services to the country. India has implemented an effective application programme to meet the national needs using its space assets. While continuing with the operational services India has been pursuing the technology developments needed for the Indian launch system, to achieve cost effective launchers as well as heavy lift launchers to inject heavier payloads. Parallely as a long-term goal progressive development of advanced technologies needed for building the cost effective space transportation systems are being taken up as technology demonstrator experiments. The brief explanation of these planned experiments are given in the paper.

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